BLOWOUT PREVENTER (BOP)
FAILURE MODE EFFECT CRITICALITY ANALYSIS (FMECA) – 1
FOR
THE BUREAU OF SAFETY AND ENVIRONMENTAL ENFORCEMENT

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SUMMARY

As part of the Blowout Preventer (BOP) Maintenance and Inspection for Deepwater Operations study (Bureau of Safety and Environmental Enforcement [BSEE] contract number M11PC00027), American Bureau of Shipping (ABS) and ABSG Consulting Inc. (ABS Consulting) performed a Failure Mode, Effect, and Criticality Analysis (FMECA) on specific BOP subsystems and equipment. There were three FMECAs performed with three different teams of operators, drilling contractors and original equipment manufacturers. This is the draft report of the FMECA conducted with Team 1 and represents the study deliverable associated with Task 6.2.2.1 as outlined in the contract.

This report presents the objective and scope of the FMECA study, FMECA methodology, FMECA results/worksheets and discusses major findings of the two workshops (Functional-level and Equipment-level) that were conducted on a selected BOP and associated equipment (Class VII BOP, 6 Rams,1 Annular) that met the study's criteria (refer to Section 1.2 Analysis Scope for more detail).

The objectives of the FMECA analysis were to (1) establish the relationship between a specific subsystem/equipment failure and a loss of system functionality, (2) identify the critical failures by using risk-ranking methods, and (3) align the current maintenance, inspection, and testing (MIT) practices and their associated frequencies with each functional failure and the associated subsystem and equipment failures.

Section 2 of the report outlines the methodology used to conduct the FMECA. The FMECA was conducted in two phases, functional-level and equipment-level. The functional-level (top-down) FMECA was conducted to identify the functional failures that could degrade the BOP functions. The equipment-level (bottom-up) FMECA was conducted to identify the impact of major equipment and component failures on the BOP performance by evaluating equipment-level failure modes, identifying specific equipment-level causes, identifying the safeguards to prevent or detect the failure modes, and ranking the criticality of failure modes. In addition, the equipment-level FMECA was used to align MIT activities with equipment-level failure modes and specific equipment failures.

In preparation for the FMECA, ABS Consulting engineers identified potential functional failures and equipment-level failure modes to help guide the analysis team. Functional- and equipment-level FMECA sessions were held with BOP subject matter experts from the original equipment manufacturer (OEM), drilling contractor, and operator. ABS Consulting and ABS engineers facilitated and documented the analysis using ABS Consulting's Enterprise LEADER software tool.

The team identified the eight BOP functions in American Petroleum Institute (API) Recommended Practices (RP) 53, Third Edition, Section 7.1.3, and one additional function prior to the FMECA analysis to meet the above objectives. During the FMECA session, it was determined that the "shear the drill pipe and seal the wellbore" function needed to be broken down into three functions based on differing operating conditions. The following 11 BOP functions were considered in the functional-level FMECA:

1. Close and seal on the drill pipe and allow circulation on demand.
2. Close and seal on open hole and allow volumetric well control operations on demand.
3. Strip the drill string using the annular BOP(s).
4. Hang-off the drill pipe on a ram BOP and control the wellbore.
5. Controlled operation – Shear the drill pipe and seal the wellbore.
6. Emergency Operation – Auto-Shear – Shear the drill pipe and seal the wellbore.
7. Emergency Operation – Emergency Disconnect System (EDS) – Shear the drill pipe and seal the wellbore.
8. Disconnect the lower marine-riser package (LMRP)/BOP.
9. Circulate the well after drill pipe disconnect.
10. Circulate across the BOP stack to remove trapped gas.
11. Connect BOP and LMRP at landing (not included API RP 53).

During the functional-level FMECA, the analysis team evaluated these 11 BOP functions and their 52 associated functional failures. Each function and its associated functional failures were evaluated in detail by identifying (1) the potential end effects resulting from the functional failure, (2) equipment-level causes and failure modes potentially resulting in the functional failure, and (3) safeguards used to prevent and/or detect the potential functional failure. Appendix A presents the Functional-level FMECA worksheets, Appendix B presents the Equipment-level FMECA worksheets.

For the equipment-level FMECA, the analysis team and industry participants (IP) identified and evaluated the following 3 major BOP subsystems and 20 major equipment categories:

1. Surface Control System
    - 1.1. Hydraulic Power Unit (HPU)
    - 1.2. Power
    - 1.3. Multiplex (MUX) System and Communication Cables
    - 1.4. Hydraulic Supply
    - 1.5. Control Panels
    - 1.6. Accumulators – Surface
    - 1.7. Fluid Reservoir Unit

2. Subsea Control System
    2.1. Blue and Yellow Control Systems – EH Section
    2.2. Blue and Yellow Control Systems – Lower Valve Section
    2.3. Accumulators – Subsea
    2.4. Emergency Control Systems (ECS)
    2.5. Secondary Control Systems (remote operated vehicle [ROV])
    2.6. Emergency Control Systems (Autoshear/Deadman)
3. BOP Stack
    3.1. Annulars
    3.2. Blind Shear Ram
    3.3. Shear Ram (Casing)
    3.4. Pipe and Test Rams
    3.5. Choke and Kill Lines and Valves
    3.6. Connectors
    3.7. Spools

Note:

1. *For the purpose of this study the "BOP System" is the first level of indenture in the BOP hierarchy (e.g. Surface Control System, Subsea Control System, BOP Stack) and "Major BOP Component" is considered the second level of indenture (e.g. MUX System, Annular).*
2. *The above naming convention was adopted during the FMECA sessions and are used throughout this FMECA report and may differ slightly from industry subsystem or equipment naming convention; see Table1-1 for additional information*

Boundaries were established to further define the major equipment items by identifying all of the components included with each major equipment item.

During the equipment-level FMECA meetings, the analysis team evaluated each major equipment item by first identifying potential equipment-level failure modes and then postulating on specific equipment failure causes resulting in each failure mode. The team then identified the potential effects resulting from each failure mode. The effects were then identified and classified into various BOP functional failures. Based on this classification the equipment-level failure modes and BOP were linked with a corresponding BOP functional failure. Once these links were established, the analysis team identified any safeguards that are currently in place to detect, prevent or mitigate the failure mode. The analysis team then identified specific MIT practices currently employed to prevent or detect the specific equipment failure causes.

In order to establish the potential risk of each equipment level failure mode, the analysis team used a Risk Priority Number (RPN) scoring methodology. The identified failure mode effects were ranked according to their severity, occurrence, and detection. The RPN for each effect (functional failure) was determined and recorded. The severity rankings were based on the worst-case end effect of each functional failure assuming that there is no redundancy. The occurrence rankings were based on the frequency of the failure mode occurring, giving credit for any system redundancy in the system(s). Finally, the detection rankings were based on the probability of the failure mode being detected by current protections (e.g. alarms) and/or current MIT practices. Appendix B contains the results of the equipment-level FMECA.

Section 3 of this report contains the analysis results. The analysis team identified and evaluated 105 functional and 121 equipment failure modes. Even though each equipment item and its mode of failure will affect the functionality of the BOP to a certain degree, the FMECA team identified the following equipment items as the most critical items contributing to the BOP's potential functional failure:

- Blind Shear Ram
- Accumulator Subsea
- Shear Ram
- Control Panels
- Secondary (ROV)
- Emergency Control Systems (Autoshear/Deadman)
- Connectors
- Blue & Yellow Control Systems - EH Section

The following table highlights the top 15% of the equipment failures that could potentially result in a severe impact on functionality of the BOP.

Table S-1: Failure Modes with Highest RPN

Major Component / Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Blind Shear Ram - BOP Stack	Mechanical Failure	10	3	7	210	18
Blind Shear Ram - BOP Stack	Loss of Function (general)	10	3	7	210	19
Accumulators - Subsea - Subsea Control Systems	Mechanical Failure (Internal wear is included)	10	2	7	140	13
Shear Ram - BOP Stack	Mechanical Failure	10	2	7	140	8
Shear Ram - BOP Stack	Loss of Function (general)	10	2	7	140	8
Control Panels - Surface Control Systems	Erratic output	10	4	3	120	15

Table S-1: Failure Modes with Highest RPN (cont'd)

Major Component / Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Control Panels - Surface Control Systems	Fails to respond to input	10	4	3	120	14
Control Panels - Surface Control Systems	Processing error	10	4	3	120	14
Secondary (ROV) - Subsea Control Systems	Loss of function (general)	10	2	6	120	10
Emergency Control Systems (Autoshear/ Deadman) - Subsea Control Systems	Loss of function (general)	10	2	6	120	8
Blind Shear Ram - BOP Stack	External Leak/ Rupture	10	3	4	120	10
Connectors - BOP Stack	Loss of Function (general)	10	1	10	100	4
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Loss of Hydraulic Power	10	3	3	90	3
Blind Shear Ram - BOP Stack	Internal Leak	10	3	3	90	9
Connectors - BOP Stack	Corrosion/ Erosion	7	2	6	84	2
Connectors - BOP Stack	Loss of Function (general)	7	2	6	84	2
Shear Ram - BOP Stack	External Leak/ Rupture	10	2	4	80	5

As identified above, the Blind Shear Ram is ranked as the top piece of equipment whose failure could potentially have a severe effect on the BOP's overall ability to function properly when demanded. Even though the occurrence of such a failure is identified as being fairly low (i.e., less than one event every 5 years to one event every 10 years), the high severity and high detection (i.e., hard to detect) increase the risk of such a failure. Therefore the Blind Shear Ram is considered to be the most critical piece of equipment that could lead to the loss of the primary function of the BOP. In this study, "loss of primary function of the BOP" is defined as controlling the well.

The high severity rating in this case is attributed to the fact that the failure of the Blind Shear Ram will diminish or eliminate the last protection for controlling the well (i.e. loss of primary function of the BOP). The high detection rating is due to the low chance of discovering such a failure during normal BOP operation. For example, mechanical failures might not be detected during normal BOP operation and could only be discovered during a major preventive or planned maintenance. As indicated in the above table, mechanical failure and general loss of function of the Blind Shear Ram resulted in 37 functional failures that could potentially result in the loss of BOP operation. Specifically, 18 functions could potentially fail due to mechanical failure and 19 functions could potentially fail due to general loss of function of Blind Shear Ram.

The Subsea Accumulators and Shear Ram ranked as the second most critical equipment items that could have an effect on the BOP's functionality and operation. The team identified 13 functional failures that contributed to the mechanical failure of the Subsea Accumulators, 8 functional failures that contributed to the mechanical failure of the Shear Ram and 8 functional failures that contributed to the loss of function of the Shear Ram. The result of these failure modes could potentially reduce or eliminate the associated equipment functionality and possibly a loss of BOP operation.

Even though in the case of the Subsea Accumulators and Shear Ram, the occurrence of such a failure was very low (less than once every 10 years), the high severity and high detection (i.e., hard to detect) increases the risk of such a failure.

According to the findings of this study, it appears that the highest critical failures are associated with the detectability of these failures. A piece of equipment might function properly during a function test or pressure test, but a hidden or dormant failure could occur because of the frequency of the test or after the tests are conducted. Additionally, some failure modes simply cannot be detected during normal testing and these types of failures may not be fully discovered until there is a real demand or the equipment is pulled from the well and inspected during major preventive maintenance.

When comparing these highly ranked failure modes with the lower ranked failure modes, it is evident that the rigorous MIT activities increase the detectability of the failures, therefore resulting in lower criticality or RPN.

During the FMECA study, the causes of each failure mode were identified. Depending on the equipment and the failure mode, components or other failure causes such as SEM communication, bolts, seals, packing elements, insufficient volume, clogged lines, loss of signal, regulators, SPM valves, shuttle valves, and filters were considered (see Appendix B for more detail). The team identified and aligned the MIT activities for each failure mode and its causes.

The occurrence and detection rankings of the failure modes are a good indication of these facts. After aligning the MIT activities with the failure modes, it was evident that there are sufficient indication and detection factors in place for mitigating the failures or reducing the criticality.

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LIST OF ACRONYMS

ABS	—	American Bureau of Shipping
ABS Consulting	—	ABSG Consulting Inc.
API	—	American Petroleum Institute
BSEE	—	Bureau of Safety and Environmental Enforcement
BOP	—	Blowout Preventer
EDS	—	Emergency Disconnect System
FMECA	—	Failure Mode, Effect, and Criticality Analysis
HPU	—	Hydraulic Power Unit
IP	—	Industry Participant
MIT	—	Maintenance, Inspection, and Test
MUX	—	Multiplex
LMRP	—	Lower Marine-Riser Package
OEM	—	Original Equipment Manufacturer
ROV	—	Remote Operated Vehicle
RP	—	Recommended Practices
RPN	—	Risk Priority Number

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1.0 INTRODUCTION

As part of the Blowout Preventer (BOP) Maintenance and Inspection for Deepwater Operations study (Bureau of Safety and Environmental Enforcement [BSEE] contract number M11PC00027), American Bureau of Shipping (ABS) and ABSG Consulting Inc. (ABS Consulting) performed a Failure Mode, Effect and Criticality Analysis on specific BOP subsystems and equipment. This report represents the first draft Failure Mode, Effect, and Criticality Analysis (FMECA) deliverable of the study associated with Task 6.2.2.1 as outlined in the contract.

Three FMECAs were performed with three different analysis teams. Each analysis team included personnel from a BOP original equipment manufacturer (OEM), drilling contractor, and an operator, with the condition that these three IPs have a working relationship and operate a drilling rig using the BOP equipment manufactured by the OEM participating in the FMECA sessions.

This report presents the objective and scope of the FMECA study, FMECA methodology and worksheets and the results of the functional- and equipment-level FMECAs that were conducted on a Class VII BOP with six Rams and one Annular. This section details the FMECA objectives, scope, and analysis team participants.

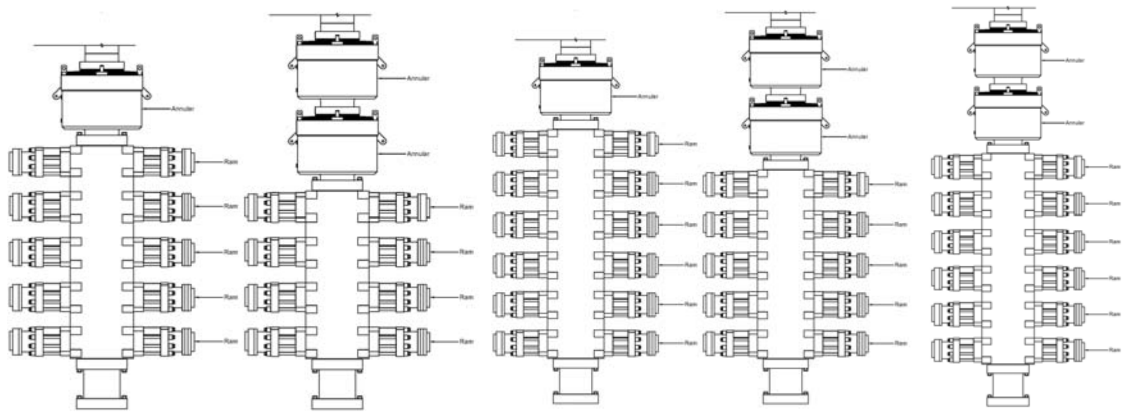
1.1 OBJECTIVES

The objectives of the FMECA were to (1) establish the relationship between a specific subsystem/equipment failure and a loss of system functionality, (2) identify the critical failures by using risk-ranking methods, and (3) align the current maintenance, inspection, and test (MIT) practices and their associated frequencies with each functional failure and the associated subsystem and equipment failures.

1.2 ANALYSIS SCOPE

The scope of this effort was the analysis of a selected BOP and associated equipment from one of the OEMs, drilling contractors and operators participating in the study that meets the following criteria:

- Operation Location – Gulf of Mexico (majority of the operation and maintenance to be from the Gulf of Mexico)
- Operating Depth – 5,000 Feet and Deeper
- BOP Configurations:
  - **Class VI BOP,** five ram configuration and single annular or a four ram and dual annular
  - **Class VII BOP,** five ram configuration and dual annular or a six ram and single annular
  - **Class VIII BOP,** six ram configuration and dual annular(ram configurations can consist of a combination of blind/shear ram, non-sealing casing ram and pipe ram preventers)



Class VI BOP Class VII BOP Class VIII BOP

The analysis included the compilation of information from IPs, followed by the review and analysis of the selected BOP and associated control systems used by the driller.

The analytical scope for the functional-level FMECA consisted for the evaluation of the eight BOP functions specified in API Recommended Practice (RP) 53 Standard, Section 7.1.3, and the additional functions identified by the analysis team. During the FMECA session, it was determined that the “shear the drill pipe and seal the wellbore” function needed to be broken down into three functions based on differing operating condition/logic. A total of 11 major BOP functions and 52 functional failures were identified and agreed upon. The following BOP functions were evaluated in this study:

1. Close and seal on the drill pipe and allow circulation on demand.
2. Close and seal on open hole and allow volumetric well control operations on demand.
3. Strip the drill string using the annular BOP(s).
4. Hang-off the drill pipe on a ram BOP and control the wellbore.
5. Controlled operation – Shear the drill pipe and seal the wellbore.
6. Emergency operation – Auto-Shear – Shear the drill pipe and seal the wellbore.
7. Emergency operation – EDS – Shear the drill pipe and seal the wellbore.
8. Disconnect the LMRP/BOP.
9. Circulate the well after drill pipe disconnect.
10. Circulate across the BOP stack to remove trapped gas.
11. Connect BOP and LMRP at Landing (not included in API RP 53 Standard).

For the equipment-level FMECA, the BOP was divided into 3 major BOP subsystems and 20 major equipment items. The following represents the selected functions and BOP systems/equipment for the FMECA assessment:

1. Surface Control System
    1.1. Hydraulic Power Unit
    1.2. Power
    1.3. Multiplex System and Communication Cables
    1.4. Hydraulic Supply
    1.5. Control Panels
    1.6. Accumulators – Surface
    1.7. Fluid Reservoir Unit
2. Subsea Control System
    2.1. Blue and Yellow Control Systems – EH Section
    2.2. Blue and Yellow Control Systems – Lower Valve Section
    2.3. Accumulators – Subsea
    2.4. Emergency Control Systems (ECS)
    2.5. Secondary Control Systems (remote operated vehicle [ROV])
    2.6. Emergency Control Systems (Autoshear/Deadman)
3. BOP Stack
    3.1. Annulars
    3.2. Blind Shear Ram
    3.3. Shear Ram (Casing)
    3.4. Pipe and Test Rams
    3.5. Choke and Kill Lines and Valves
    3.6. Connectors
    3.7. Spools

In addition, boundaries were established for each major equipment item to identify all of the specific components to be included with each major equipment item. Table 1-1 lists the boundaries used in this specific analysis.

Table 1-1: Equipment-Level FMECA Major Component Boundaries

Major Component	Specific Components Included with Major Component Boundary
Surface Control System	
Hydraulic power unit (HPU)	HPU including three HPU pumps and associated piping and regulators
Power	Power including Blue & Yellow Power Distribution Panels, Power Isolation J-box; Blue & Yellow UPSs, Blue & Yellow Subsea Transformers, and blue and yellow distribution panels, umbilical J-box; and connections to associated cabinets and equipment (e.g., multiplex [MUX], control panels)
MUX System Communication Cables	MUX System, including Central Control Unit with process array, blue & yellow processor array, and associated equipment and cabinets; MUX cable reels and MUX cables (to connections with Blue & Yellow Pods)

Table 1-1: Equipment-Level FMECA Major Component Boundaries (cont'd)

Major Component	Specific Components Included with Major Component Boundary
Hydraulic Supply	Hydraulic Supply including blue & yellow hotline reels, hotline hoses (to connection at Blue & Yellow Pods) and rigid conduit (to connection with subsea accumulator system)
Control Panels	Control Panels including driller's panel with system controller and tool pusher's panel with system controller
Accumulators – Surface	Accumulators - Surface including one 300 gallon, 5K rack; one 180 gallon 5K accumulator rack and associated ball valve; and connectors to HPU
Fluid Reservoir Unit	Fluid Reservoir Unit, including 650 gallon. glycol, 550 gallon concentrate, and 1350 gallon mixed fluid reservoirs; glycol, concentrate, and mixed fluid pumps; and associated piping, and mixing system
Subsea Control System	
Blue & Yellow Control Systems – EH Section	Blue & Yellow Control Systems including MUX control, MUX POD power & communication, hydraulic connections within the pod, E/H section (hydraulics, power, communication, SEM interface, pressure, temperature, and water sensors, transformer, pod cabling, solenoid boards, solenoids.
Blue & Yellow Control Systems – Lower Valve Section	Blue & Yellow Control Systems - Lower Valve Section including regulators and SPM valves to the shuttle valve
Accumulators – Subsea	Accumulators - Subsea including associated hydraulic piping and connections such as MUX pod and rigid conduit connections, 16x 80gallon bottles
EDS	Secondary & Emergency Control Systems - Subsea including POD angle sensor, inclinometer, acoustic, and deadman
Secondary Control Systems (ROV)	Secondary & Emergency Control Systems - Subsea including POD angle sensor, inclinometer, acoustic, and deadman
Emergency Control Systems (Autoshear/Deadman)	Secondary & Emergency Control Systems - Subsea including POD angle sensor, inclinometer, acoustic, and deadman
BOP Stack	
Annulars	Blowout preventer that uses a shaped elastomeric sealing element to seal the space between the tubular and the wellbore or an open hole, including both lower and upper annulars and hydraulic supply
Blind Shear Ram	Ram BOP whose Ram Blocks incorporate a cutting blade to shear the pipe and sealing elements to contain well bore pressure upon shearing of the pipe, including hydraulic supply
Shear Ram	Ram BOP whose Ram Blocks incorporate a cutting blade to cut casing and/or heavier grade tubulars within a specific range. They do not seal the well bore.

Table 1-1: Equipment-Level FMECA Major Component Boundaries (cont'd)

Major Component	Specific Components Included With Major Component Boundary
Pipe & Test Rams	**Pipe Ram:** A closing and sealing component in a ram blowout preventer that seals around the outside diameter of a tubular in the wellbore. **Test Ram**: A Variable Bore Ram located in the lower most Ram Cavity with ram block installed in inverted position to seal pressure from the top and enable testing of the BOP Stack without running a Test Tool.
Choke & Kill Lines & Valves	Valves and pipes assembly enabling communication to or from the well bore to the surface C&K manifold to circulate well, control kicks or kill well. Choke & Kill Lines & Valves on both LMRP & Stack.
Connectors	Connectors at Wellhead and LMRP/BOP Stack and Hydraulic Actuators
Spool	Spacer Spools including connections to other BOP stack equipment

1.3 FMECA TEAM MEMBERS AND MEETING SCHEDULE

The analysis team for this study included personnel from three industry participants (IPs), ABS, and ABS Consulting. The IPs participating included one or more representatives from an OEM, drilling contractor, and operator. These individuals provided knowledge of the design, engineering, operation, and maintenance of the BOP being evaluated. Table 1-2 lists the functional positions for the IP personnel who participated in this study.

Table 1-2: IP FMECA Team Members

IP Organization	Position/Expertise
BOP OEM	Engineering Manager, Drilling Products
	Manager, Reliability Engineering/Drilling and Production
	Electrical Engineering Manager, Drilling and Production
	Sub Section Manager, Stacks, Mechanical Controls and Risers
Drilling Contractor	Corporate Subsea Operation Manager
	Subsea Superintendent
	Subsea MUX System subject matter expert
Operator	Subsea Intervention Engineer
	Engineer Operations, Drilling and Completions

In addition to the IP representatives, personnel from ABS and ABS Consulting participated in the FMECA sessions. Specifically, ABS personnel provided knowledge of the overall BOP operations and class society and regulatory requirements applicable to BOP design and operation. ABS Consulting personnel facilitated and documented the FMECA study. Table 1-3 lists the ABS and ABS Consulting personnel participating in this study.

Table 1-3: ABS and ABS Consulting FMECA Team Members

Name	Organization	Title	Study Role
David Cherbonnier	ABS	Staff Consultant, Corporate Offshore Technology	Subsea Engineer
Bibek Das	ABS	Senior Engineer II, Corporate Shared Technology	Senior Engineer II (Risk and Reliability), Corporate Technology
Randy Montgomery	ABS Consulting	Senior Director, Integrity Management	Project Technical Lead
Kamran Nouri	ABS Consulting	Senior Risk and Reliability Engineer	Workshop Facilitator
Andrew Quillin	ABS Consulting	Lead Engineer	Workshop Scribe
Harish Patel	ABS	Manager, Corporate Technology - Drilling and Process	Overall Project Manager

To prepare for the FMECA studies, ABS and ABS Consulting held a FMECA kickoff meeting with the IPs on August 14 and 15, 2012. The purposes of the kickoff meeting were to discuss the FMECA analysis approach and the analysis scope to help ensure that all participants have the same level of understanding of the FMECA procedures.

The functional-level FMECA study was conducted by the analysis team during sessions held on September 10 through 12, 2012. During this meeting, the analysis team members were provided an introduction to FMECA methodology and procedures and then performed the functional-level FMECA. The equipment-level FMECA was conducted during sessions held on September 24 through 28, 2012.

1.4 REPORT ORGANIZATION

Section 2 of this report provides an overview of the methodology used to analyze the BOP's selected functions and equipment to determine the critical failure modes and their effects. Section 3 discusses the results of the effort. Appendix A contains the functional-level FMECA worksheets and Appendix B contains the equipment-level FMECA worksheets.

2.0 ANALYSIS METHODOLOGY

In order to evaluate BOP MIT practices, reduce the risk of failures and improve the reliability of BOP performance, it is essential to identify the BOP's critical failure modes and their effects. Therefore, ABS and ABS Consulting selected and employed both functional- and equipment-level FMECA methodologies to evaluate BOP functions and identify specific subsystem and equipment failures of interest as outlined in Section 1.2, Analysis Scope.

This analysis methodology was chosen because it provided a means to establish a relationship among (1) BOP functions, (2) BOP equipment failures, and (3) BOP MIT practices by

- Identifying the potential effects resulting from deviations to BOP functions (i.e., functional failures) and equipment-level failure modes causing the BOP functional failures.
- Identifying the potential functional failures resulting from BOP equipment failure modes and specific equipment failures causing the BOP equipment failure modes.
- Linking specific equipment failures to BOP functional failures.
- Identifying and aligning the MIT activities (Indication / Protection / Maintenance) currently provided for preventing specific equipment failures resulting in BOP functional failures and their potential end effects.
- Risk-ranking the equipment-level failure modes.

2.1 ANALYSIS APPROACH

FMECA is an inductive reasoning approach that (1) considers how the functional failures of each system function or the failure modes of each component could result in system performance problems and (2) helps evaluate safeguards that are in place (including engineered protections & monitoring systems, human actions, and maintenance activities) to prevent, detect or mitigate such problems. The main focus of a FMECA is to establish the cause-and-effect relationship between potential equipment failures, functional failures, and the end effect of those failures, and to evaluate the criticality of the postulated functional failure/failure mode.

Figure 2-1 represents the general FMECA steps used in evaluating the BOP system. Specifically, this study employed both functional- and equipment-level FMECA approaches (see Step 3) with the explicit purpose of transitioning the functional-level FMECA to a more detailed level to better ensure the alignment of MIT activities with specific equipment failures and link the specific equipment failures with their potential impact of BOP performance via functional failures. This FMECA approach is very similar to the approach employed in many classical reliability-centered maintenance approaches, which have the overall objective of determining the optimal maintenance strategy for preserving system functionality via detection and prevention of equipment failures.

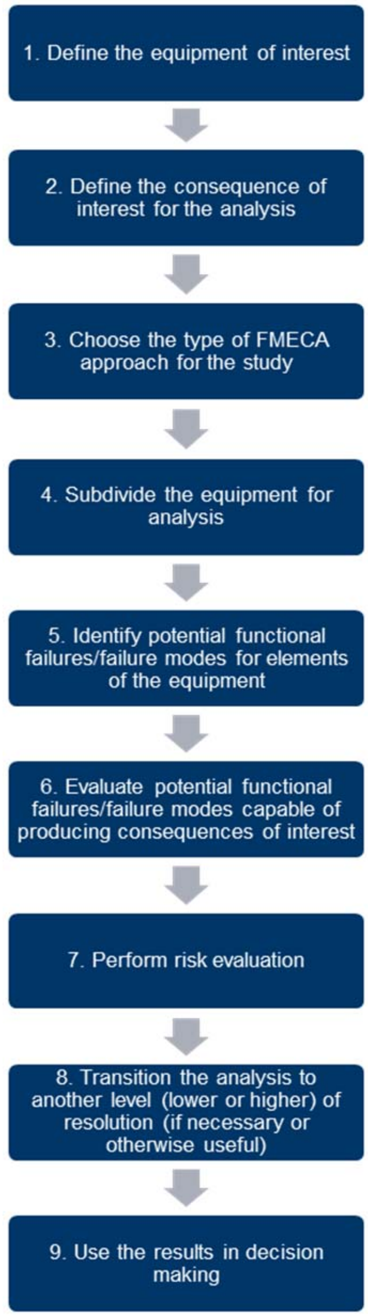


Figure 2-1. General FMECA Approach

2.2 ANALYSIS PROCEDURES

This section summarizes the procedures and specific tools used in performing the functional- and equipment-level FMECAs. In addition, the risk priority number approach that was used to risk rank the functional failure effects and equipment failure mode pairs has been provided. More explanation on the ranking method is given in Section 2.2.3.

2.2.1 Functional Level (Top-down) FMECA

The functional-level FMECA was performed by analyzing each function and its associated functional failures. The functional-level FMECA process is illustrated in Figure 2-2. In executing this procedure, the following operating modes were applied:

- Normal Drilling
- Kick Control
- Emergency Operation (e.g., disconnect)
- Riding the Storm

In addition, the following are consequences of interest for identifying end effects of interest during the functional-level FMECA:

- Safety Effects
  - Inability to Control or Correct a Well Kick (or other BOP function)
  - Potential Release of Hydrocarbon to the Atmosphere Resulting in Potential Fire, Explosion, and/or Exposure to Toxic Materials Causing Injury or Worse
- Environmental Effects
  - Inability to Control or Correct a Well Kick (or other BOP function)
  - Potential Release of Hydrocarbons to the environment resulting in a Minor, Significant, Small (<1,000 bbls), Medium (1,000 to 10,000 bbl.), or Large (>10,000 bbl.) Spill/Atmospheric Release
- Significant Downtime
  - Failures Requiring Pulling of the LMRP or BOP Stack
  - Downtime Exceeding 5 Days

In evaluating potential end effects, the team evaluated the severities based on worst-case end effects assuming that available safeguards do not prevent or mitigate the end effects. Therefore, the end effects represent the potential severity and conservatively overstate the expected consequences.

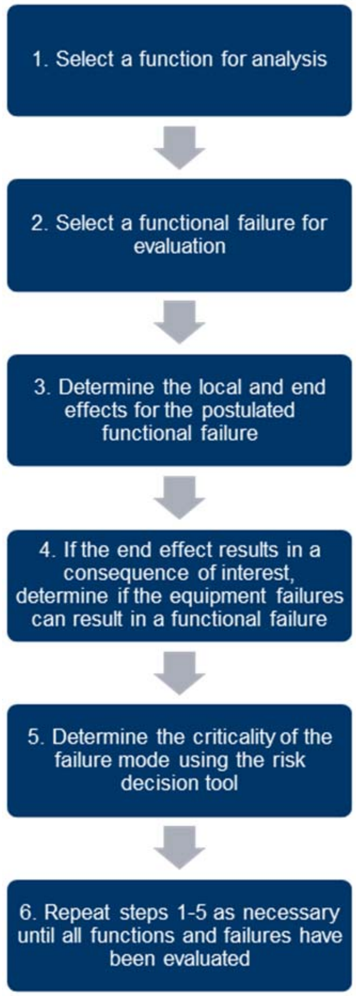


Figure 2-2. Functional-level FMECA Procedure

Specifically during the functional-level FMECA, the analysis team evaluated 11 BOP functions and 52 associated functional failures. Table 2-1 list the functions and functional failures evaluated.

Table 2-1: Functions and Functional Failures

No.	Function	Functional Failure Modes
1	Close and seal on the drill pipe and allow circulation on demand	Failure to close on drill pipe through annular(s)
		Failure to close on drill pipe through pipe rams
		Failure to seal or partial seal on drill pipe through annular(s)
		Failure to seal or partial seal on drill pipe through pipe rams
		Unintentional closing / opening
		Failure to open/close fail-safe valves to seal
		Closes too slowly
		Loss of containment
2	Close and seal on open hole and allow volumetric well control operations on demand	Failure to close on open hole through blind-shear rams or annular
		Unintentional closing / opening
		Failure to open/close fail-safe valves
		Closes too slowly
		Loss of containment
3	Strip the drill string using the annular BOP(s)	Failure to close annulars
		Failure to maintain stripping pressure
		Failure to seal
4	Hang-off the drill pipe on a ram BOP and control the wellbore	Failure of hang-off ram to close
		Failure to maintain closing pressure
		Failure to maintain locking
5	Controlled Operation-Shear the drill pipe and seal the wellbore	Failure to close
		Failure to shear the drill pipe
		Failure to seal the wellbore
		Unintentional closing / opening
		Closes too slowly
		Loss of containment
6	Emergency Operation-Auto shear-Shear the drill pipe and seal the wellbore	Failure to arm
		Failure to close
		Failure to shear the drill pipe
		Failure to seal the wellbore
		Unintentional closing / opening
		Closes too slowly
		Loss of containment
7	Emergency Operation-EDS- Shear the drill pipe and seal the wellbore	Failure to close
		Failure to shear the drill pipe
		Failure to seal the wellbore
		Unintentional closing / opening
		Closes too slowly
		Loss of containment
		Failure to disconnect the LMRP

Table 2-1: Functions and Functional Failures (cont'd)

No.	Function	Functional Failure Modes
8	Disconnect LMRP/BOP	Failure to disconnect the LMRP/BOP
		Unintentional disconnect of the LMRP/BOP
9	Circulate the well after drill pipe disconnect	Failure to circulate
		Failure to circulate at desired flow rate
		Failure to open/close fail-safe valves
		Failure to seal wellbore after drill pipe disconnect
		Loss of containment
10	Circulate across the BOP stack to remove trapped gas	Failure to circulate
		Failure to circulate at desired flow rate
		Failure to open/close fail-safe valves
		Loss of containment
11	Connect BOP and LMRP at landing	Inadequate BOP connection
		Inadequate LMRP connection

During the functional-level FMECA workshop, the analysis team evaluated each of the above-mentioned functions and functional failures in detail by identifying (1) the potential end effects resulting from the functional failures, (2) the equipment-level causes and failure modes resulting in each potential functional failure, and (3) the safeguards used to prevent or detect the potential functional failure and its associated equipment-level causes. These evaluations were recorded in tabular format using the Enterprise LEADER software. The equipment-level causes and failure modes were then studied in detail during the equipment-level FMECA workshop.

2.2.2 Equipment Level (Bottom-up) FMECA

The equipment-level FMECA was performed by analyzing each major component with its associated sub-components using equipment-level failure modes. Figure 2-3 outlines the equipment-level FMECA process.

The analysis team evaluated the 20 major equipment items and their associated sub-components listed in Table 1-1.

To evaluate each equipment item, a list of the general failure modes was developed during the FMECA kick-off meeting and is provided in Table 2-2. During the equipment-level FMECA, the analysis team modified these general equipment failure modes to describe the means in which each major component can fail.

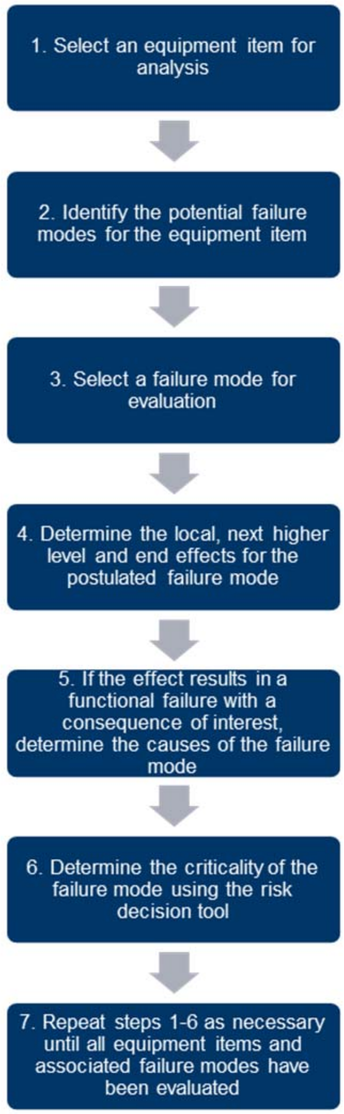


Figure 2-3. FMECA Bottom-up Procedures

Table 2-2: General Equipment Failure Modes

Mechanical Failures	Electrical/Electronics Failure
External leak/rupture	Loss of, or degraded power
Internal leak	Fails with no output signal/no communication
Plugged	Fails with low or high output signal
Mechanical failure (e.g., fracture, galling, fatigue)	Erratic output
Corrosion/erosion	Fails to respond to input
Wear/mechanical damage	Processing error (e.g., calculation error, sequence error)
Loss of function (general)	Short
Loss of hydraulic power	Loss of function (general)

Once a major component's failure modes were identified, the analysis team evaluated each equipment-level failure mode by:

1. Postulating on specific equipment causes resulting in the failure mode and
2. Then identifying the potential effects resulting from each failure mode.

The equipment-level effects were identified as BOP functional failures and then electronically linked in Enterprise LEADER to establish the relationship between specific equipment-level failure modes and BOP functions. Once these links were established, the analysis team identified any safeguards that are currently in place to prevent or detect or mitigate the failure mode before the end effects associated with the BOP functional failure are realized. Next, the analysis team identified specific MIT practices currently employed to prevent or detect the specific equipment causes. These evaluations, along with criticality rankings described below, were recorded in tabular format using the Enterprise LEADER software.

2.2.3 Evaluation and Ranking of Equipment Failure Modes (Criticality/Risk Ranking)

To provide a consistent means to evaluate the relative criticality of BOP subsystem/component failures and to help judge the sufficiency of MIT activities performed to prevent and detect the failures, a risk priority number ranking scheme based the following factors was employed:

- Frequency of Failure of the Major Equipment Failure Mode
- Level of Redundancy to Prevent Specific Failure from Resulting in Complete Loss of Safety Critical Functions
- Ability to Detect and Prevent the Failure Mode via MIT Practices (Indication / Protection / Maintenance column in Appendix B)
- Severity of End Effect for Each BOP Functional Failure

A risk priority number (RPN) ranking for each functional failure associated with an equipment-level failure mode was based on the product of the following three independent factors:

- Severity Rating – This rating assesses the severity of worst-case end effect for a given functional failure. (Note: The functional failure end effects documented in the functional-level FMECA were used to determine this rating assuming no redundancies are present.)
- Occurrence Rating – This rating assesses the likelihood of the failure mode resulting in the functional failure and its stated end effect. This rating takes into consideration any safeguards that are in place to detect, prevent or mitigate the failure mode from resulting in the functional failure. These are the Protection (P) items in the Indication / Protection / Maintenance column of Appendix B. The presence of redundant components and systems is explicitly considered in this rating.

- Detection Rating – This rating assesses the likelihood of the current applicable inspection and maintenance activities to detect the failure mode before it results in the functional failure. These ratings are based on the Indication (I) and Maintenance (M) items from the Indication / Protection / Maintenance column of Appendix B.

The severity, occurrence, and detection ratings are provided in Tables 2-3 through 2-5, respectively. These ratings were then used to calculate a single RPN ranking for each functional failure effect and equipment failure mode pair (i.e., RPN ranking for each functional failure associated with an equipment-level failure mode) using the following equation:

RPN = Severity Rating X Occurrence Rating X Detection Rating

The individual RPN rankings provide a relative ranking of the risk associated with a given functional failure effect-equipment failure mode pair. Thereby, providing a means to identify the most critical equipment-level failure modes in overall BOP performance, as well as, identifying the more critical failure modes associated with a specific BOP functional failure.

Table 2-3: Severity Ratings

Severity Rank	Significance	Personnel	Environment	Down Time
1	Does not affect BOP functionality; no impact on safety and environment.	No impact	No impact	No downtime, repair can be done while drilling continues.
2	Does not affect BOP functionality but needs to be corrected; no impact on safety and environment.	No impact	No impact	No downtime, repair can be done at next opportunity, drilling continues.
3	Partial loss of BOP function; no loss of well control.	No impact	No impact	Downtime of less than a shift, stop drilling, intervene and repair.
4	Partial loss of BOP function; no loss of well control.	No impact	No impact	Downtime between a shift and 24 hours, stop drilling, intervene and repair.
5	Partial loss of BOP primary function if not corrected immediately.	No impact	No impact	Downtime between 1 and 7 days - stop drilling, intervene and repair (surface only).
6	Partial loss of BOP primary function if not corrected immediately.	Minor Injury; no recordable lost time	Minor external subsea leak (e.g., C&K connector leak)	Downtime between 8 and 21 days - stop drilling, intervene and repair (surface only).

Table 2-3: Severity Ratings (cont'd)

Severity Rank	Significance	Personnel	Environment	Down Time
7	Loss of BOP primary function.	Minor Injury; some lost time.	Significant external subsea leak (e.g., major connector leak)	Pulling LMRP only.
8	Loss of BOP primary function.	Serious Injury; significant lost time.	<1000 BBL	Pulling LMRP/BOP stack.
9	Loss of BOP primary function.	Single Fatality; multiple serious injuries.	>1000BBL	Shut down of operations; drilling stopped and major regulatory implications; changes to drilling schedule > 3 months.
10	Loss of BOP primary function.	Multiple fatalities and injuries.	>10,000BBL and severe environmental damage over a large area.	Shut down of operations; drilling stopped and major regulatory implications; total loss of asset.

Table 2-4: Occurrence Ratings

Occurrence Ratings	Frequency/Rig Yr.	Occurrence
10	>50+ events/ rig yr.	Once a week or more often
9	<50 events /rig yr. to 10 events /rig yr.	Less than once a week to once a month
8	<10 events /rig yr. to 4 events /rig yr.	Less than once a month to once a quarter
7	<4 events /rig yr. to 2 events /yr.	Less than once a quarter to twice a year
6	<2 events /rig yr. to 1 event/yr.	Less than twice a year to once a year
5	<1 event /rig yr. to 1 events every 2 years	Less than once a year to once every 2 years
4	<1 event every 2 years to 1 event every 5 years	Less than once every 2 years to once every 5 years
3	<1 event every 5 years to 1 event every 10 years	Less than once every 5 years to once every 10 years
2	<1 event every 10 years to 1 event every 100 years	Less than once every 10 years to 10% chance every 10 years of operation
1	<1 event every 100 years	Less than 1% chance every 10 years of operation

Table 2-5: Detection Ratings

Detection Rating	Detection	Likelihood of Detection
1	Almost Certain	Very high probability of detection (>90% probability of detection) by design controls (redundant or independent self-diagnostic capability, independent alarms) will certainly detect failures
2	Very High	High probability of detection (50 to 90% of detection) by design controls (single device self-diagnostic capability, single alarms, visual monitoring, leak monitoring, loss of fluid etc.) will certainly detect failures
3	High	Probability of detection via weekly on-stream tests/inspections will provide immediate detection of the failure
4	Moderately high	Probability of detection via monthly on-stream tests/inspections will provide immediate detection of the failure
5	Moderate	Probability of detection via quarterly on-stream tests/inspections will provide immediate detection of the failure
6	Low	Can only be detected during routine inspections/tests while the BOP is pulled from the well
7-8	Very Low	Can only be detected during major PMs while the BOP is pulled from the well
9	Remote	Can only be detected and/or corrected during major overhaul or rebuilding-type activities
10	Absolute Uncertainty	Currently no design controls or maintenance techniques in place

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3.0 FMECA RESULTS

This section summarizes the results of the FMECA analysis—specifically, the results of the functional-level and equipment-level FMECAs which are provided in tabular format in Appendices A and B, respectively. These appendices also include a description of the FMECA table information.

In addition to the tabular results provided in the above-mentioned appendices, the following tables provide a more detailed look at the most critical failure modes based on the RPN rankings. Each of the following tables presents the results against a specific set of criteria described below. The complete data from which these tables have been derived is provided in Appendices C and D, which are essentially a reformatted presentation of Appendix B. In each of the following tables, the shaded column indicates the sorting order.

Table 3-1 presents the top 15% of failure modes with the highest RPN score. RPN scores from the FMECA range from 4–210, with the top 15% ranging from 80–210. Tables 3-1a and 3-1b present the same data but are sorted differently; Table 3-1a is sorted by RPN and Table 3-1b is sorted by Equipment/Subsystem. Table 3-1 represents what are considered to be the most critical failure modes. It should be noted that each failure mode may be associated with multiple effects/functional failures as shown in the last column of the tables. Table 3-1b suggests that a failure of the Blind-Shear Ram is the most dominant equipment of concern.

Table 3-1a: Failure Modes with Highest RPN – Sorted by RPN

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Blind Shear Ram - BOP Stack	Mechanical Failure	10	3	7	210	18
Blind Shear Ram - BOP Stack	Loss of Function (general)	10	3	7	210	19
Accumulators - Subsea - Subsea Control Systems	Mechanical Failure (Internal wear is included)	10	2	7	140	13
Shear Ram - BOP Stack	Mechanical Failure	10	2	7	140	8
Shear Ram - BOP Stack	Loss of Function (general)	10	2	7	140	8
Control Panels - Surface Control Systems	Erratic output	10	4	3	120	15
Control Panels - Surface Control Systems	Fails to respond to input	10	4	3	120	14
Control Panels - Surface Control Systems	Processing error	10	4	3	120	14
Secondary (ROV) - Subsea Control Systems	Loss of function (general)	10	2	6	120	10
Emergency Control Systems (Autoshear/ Deadman) - Subsea Control Systems	Loss of function (general)	10	2	6	120	8
Blind Shear Ram - BOP Stack	External Leak / Rupture	10	3	4	120	10

Table 3-1a: Failure Modes with Highest RPN – Sorted by RPN (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Connectors - BOP Stack	Loss of Function (general)	10	1	10	100	4
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Loss of Hydraulic Power	10	3	3	90	3
Blind Shear Ram - BOP Stack	Internal Leak	10	3	3	90	9
Connectors - BOP Stack	Corrosion/ Erosion	7	2	6	84	2
Connectors - BOP Stack	Loss of Function (general)	7	2	6	84	2
Shear Ram - BOP Stack	External Leak/ Rupture	10	2	4	80	5

Table 3-1b: Failure Modes with Highest RPN – Sorted by Item Index

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Control Panels - Surface Control Systems	Erratic output	10	4	3	120	15
Control Panels - Surface Control Systems	Fails to respond to input	10	4	3	120	14
Control Panels - Surface Control Systems	Processing error	10	4	3	120	14
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Loss of Hydraulic Power	10	3	3	90	3

Table 3-1b: Failure Modes with Highest RPN – Sorted by Item Index (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Accumulators - Subsea - Subsea Control Systems	Mechani-cal Failure (Internal wear is included)	10	2	7	140	13
Secondary (ROV) - Subsea Control Systems	Loss of function (general)	10	2	6	120	10
Emergency Control Systems (Autoshear/Dead man) - Subsea Control Systems	Loss of function (general)	10	2	6	120	8
Blind Shear Ram - BOP Stack	External Leak / Rupture	10	3	4	120	10
Blind Shear Ram - BOP Stack	Internal Leak	10	3	3	90	9
Blind Shear Ram - BOP Stack	Mechanica l Failure	10	3	7	210	18
Blind Shear Ram - BOP Stack	Loss of Function (general)	10	3	7	210	19
Shear Ram - BOP Stack	External Leak/ Rupture	10	2	4	80	5
Shear Ram - BOP Stack	Mechani-cal Failure	10	2	7	140	8
Shear Ram - BOP Stack	Loss of Function (general)	10	2	7	140	8
Connectors - BOP Stack	Corrosion/ Erosion	7	2	6	84	2
Connectors - BOP Stack	Loss of Function (general)	10	1	10	100	4
Connectors - BOP Stack	Loss of Function (general)	7	2	6	84	2

Table 3-2 shows the equipment failure modes which could lead to the worst potential end effects. These are the failure modes with a severity ranking greater than or equal to 5. Severity results from this FMECA range from 4 – 10.

Table 3-2: Failure Modes with Severity ≥ 5

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
HPU - Surface Control Systems	External Leak/Rupture	10	1	3	30	32
HPU - Surface Control Systems	Internal Leak	10	1	6	60	18
HPU - Surface Control Systems	Plugged	10	1	3	30	13
HPU - Surface Control Systems	Mechanical Failure	10	1	3	30	13
HPU - Surface Control Systems	Loss of Function (general)	10	1	3	30	37
Power - Surface Control Systems	Loss of or Degraded Power (System Blackout)	10	1	1	10	12
Power - Surface Control Systems	Fails to Respond to Input	10	2	1	20	12
Power - Surface Control Systems	Electrical Short	10	1	2	20	12
MUX System Communication Cables - Surface Control Systems	Fails with no output signal/communication	10	2	2	20	3

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
MUX System Communication Cables - Surface Control Systems	Fails with no output signal/communication	10	2	2	40	15
MUX System Communication Cables - Surface Control Systems	Erratic output (Network)	10	2	2	40	18
MUX System Communication Cables - Surface Control Systems	Communications Short/ Open Circuit	10	1	2	20	13
Hydraulic Supply - Surface Control Systems	External Leak/ Rupture	10	2	2	40	13
Hydraulic Supply - Surface Control Systems	Mechanical Failure	10	2	1	20	13
Hydraulic Supply - Surface Control Systems	Loss of Supply	10	1	2	20	12
Control Panels - Surface Control Systems	Loss of Power	10	1	1	10	12
Control Panels - Surface Control Systems	Fails with no output signal/communication	10	1	2	20	13

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Control Panels - Surface Control Systems	Erratic output	10	2	3	60	5
Control Panels - Surface Control Systems	Erratic output	10	4	3	120	15
Control Panels - Surface Control Systems	Fails to respond to input	10	2	3	60	4
Control Panels - Surface Control Systems	Fails to respond to input	10	4	3	120	14
Control Panels - Surface Control Systems	Processing error	10	2	3	60	4
Control Panels - Surface Control Systems	Processing error	10	4	3	120	14
Accumulators - Surface - Surface Control Systems	External Leak/ Rupture	10	1	3	30	1
Accumulators - Surface - Surface Control Systems	Internal Leak	10	1	3	30	1
Accumulators - Surface - Surface Control Systems	Plugged	10	1	3	30	1
Accumulators - Surface - Surface Control Systems	Mechanical Failure (Internal wear is included)	10	1	3	30	1

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Accumulators - Surface - Surface Control Systems	Loss of Function (general)	10	1	3	30	6
Fluid Reservoir Unit - Surface Control Systems	External Leak/ Rupture	10	1	2	20	13
Fluid Reservoir Unit - Surface Control Systems	Internal Leak	10	1	2	20	18
Fluid Reservoir Unit - Surface Control Systems	Plugged	10	1	3	30	13
Fluid Reservoir Unit - Surface Control Systems	Mechanical Failure	10	1	2	20	13
Fluid Reservoir Unit - Surface Control Systems	Loss of Function (general)	10	1	2	20	13
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Loss of or Degraded Electrical Power	10	2	1	20	15
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Fails with no output signal/com-munication	10	1	2	20	13

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Erratic output	10	2	2	40	12
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Loss of Hydraulic Power	10	3	3	90	3
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	External Leak	10	2	3	60	24
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Internal Leak	10	1	3	30	19
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Plugged	10	1	3	30	24
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Mechanical Failure	10	1	3	30	21

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Corrosion / Erosion - No Indication of Corrosion / Erosion (Stainless Steel)	10	1	6	60	13
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Loss of Function (general)	10	1	3	30	43
Accumulators - Subsea - Subsea Control Systems	External Leak / Rupture	10	2	3	60	13
Accumulators - Subsea - Subsea Control Systems	Internal Leak	10	1	6	60	26
Accumulators - Subsea - Subsea Control Systems	Plugged	10	2	3	60	12
Accumulators - Subsea - Subsea Control Systems	Mechanical Failure (Internal wear is included)	10	2	7	140	13
Emergency Control Systems (EDS) - Subsea Control Systems	Loss of or Degraded Power	10	2	2	40	13
Secondary (ROV) - Subsea Control Systems	Loss of function (general)	10	2	6	120	10

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Emergency Control Systems (Autoshear/ Deadman) - Subsea Control Systems	Electrical Failure (Failure to Arm)	10	2	2	40	10
Emergency Control Systems (Autoshear/ Deadman) - Subsea Control Systems	Hydraulic Failure (Failure to Arm and Maintain Arming)	10	1	2	20	4
Emergency Control Systems (Autoshear/ Deadman) - Subsea Control Systems	Loss of function (general)	10	2	6	120	8
Annulars - BOP Stack	External Leak/ Rupture	10	1	3	30	12
Annulars - BOP Stack	Internal Leak	10	1	3	30	8
Annulars - BOP Stack	Plugged	10	1	3	30	2
Annulars - BOP Stack	Mechanical Failure	10	1	3	30	12
Annulars - BOP Stack	Wear	10	1	6	60	10
Annulars - BOP Stack	Corrosion / Erosion	10	1	6	60	2
Annulars - BOP Stack	Loss of Function (general)	10	1	6	60	10
Blind Shear Ram - BOP Stack	External Leak/ Rupture	10	3	4	120	10

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Blind Shear Ram - BOP Stack	Internal Leak	10	3	3	90	9
Blind Shear Ram - BOP Stack	Plugged	10	2	3	60	6
Blind Shear Ram - BOP Stack	Mechanical Failure	10	3	7	210	18
Blind Shear Ram - BOP Stack	Wear	10	1	6	60	12
Blind Shear Ram - BOP Stack	Corrosion/ Erosion	10	1	6	60	5
Blind Shear Ram - BOP Stack	Loss of Function (general)	10	3	7	210	19
Shear Ram - BOP Stack	External Leak/ Rupture	10	2	4	80	5
Shear Ram - BOP Stack	Internal Leak	10	1	3	30	3
Shear Ram - BOP Stack	Plugged	10	1	3	30	4
Shear Ram - BOP Stack	Mechanical Failure	10	2	7	140	8
Shear Ram - BOP Stack	Wear	10	1	6	60	2
Shear Ram - BOP Stack	Corrosion/ Erosion	10	1	6	60	2
Shear Ram - BOP Stack	Loss of Function (general)	10	2	7	140	8
Pipe & Test Rams - BOP Stack	External Leak/ Rupture	10	1	3	30	7
Pipe & Test Rams - BOP Stack	Internal Leak	10	1	3	30	3
Pipe & Test Rams - BOP Stack	Plugged	10	1	3	30	3

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Pipe & Test Rams - BOP Stack	Mechanical Failure	10	1	3	30	10
Pipe & Test Rams - BOP Stack	Wear	10	1	6	60	6
Pipe & Test Rams - BOP Stack	Corrosion/ Erosion	10	1	6	60	5
Pipe & Test Rams - BOP Stack	Loss of Function (general)	10	1	3	30	6
Choke & Kill Lines & Valves - BOP Stack	External Leak/ Rupture	10	1	3	30	7
Choke & Kill Lines & Valves - BOP Stack	Internal Leak	10	1	3	30	10
Choke & Kill Lines & Valves - BOP Stack	Plugged	10	1	3	30	6
Choke & Kill Lines & Valves - BOP Stack	Mechanical Failure	10	1	2	20	13
Choke & Kill Lines & Valves - BOP Stack	Wear	10	1	6	60	8
Choke & Kill Lines & Valves - BOP Stack	Corrosion/ Erosion	10	1	6	60	6
Choke & Kill Lines & Valves - BOP Stack	Loss of Function (general)	10	1	3	30	2
Connectors - BOP Stack	External Leak/ Rupture	10	1	2	20	9

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Connectors - BOP Stack	Internal Leak	10	1	6	60	4
Connectors - BOP Stack	Mechanical Failure	10	1	6	60	9
Connectors - BOP Stack	Loss of Function (general)	10	1	10	100	4
Spools - BOP Stack	External Leak	10	1	2	20	7
Spools - BOP Stack	Mechanical Failure	10	1	2	20	7
Connectors - BOP Stack	External Leak/ Rupture	8	1	2	16	1
Connectors - BOP Stack	Corrosion/ Erosion	8	1	6	48	2
Connectors - BOP Stack	Loss of Function (general)	8	1	6	48	2
Connectors - BOP Stack	External Leak/ Rupture	7	2	2	28	1
Connectors - BOP Stack	Corrosion/ Erosion	7	2	6	84	2
Connectors - BOP Stack	Loss of Function (general)	7	2	6	84	2
HPU - Surface Control Systems	External Leak / Rupture	5	1	3	15	2
HPU - Surface Control Systems	Internal Leak	5	1	6	30	1
HPU - Surface Control Systems	Plugged	5	1	3	15	1
HPU - Surface Control Systems	Mechanical Failure	5	1	3	15	1
HPU - Surface Control Systems	Loss of Function (general)	5	1	3	15	3

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Accumulators - Surface - Surface Control Systems	External Leak/ Rupture	5	1	3	15	12
Accumulators - Surface - Surface Control Systems	Internal Leak	5	1	3	15	17
Accumulators - Surface - Surface Control Systems	Plugged	5	1	3	15	12
Accumulators - Surface - Surface Control Systems	Mechanical Failure (Internal wear is included)	5	1	3	15	13
Accumulators - Surface - Surface Control Systems	Loss of Function (general)	5	1	3	15	12
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	External Leak	5	2	3	30	1
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Plugged	5	1	3	15	1

Table 3-2: Failure Modes with Severity ≥ 5 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Loss of Function (general)	5	1	3	15	2
Accumulators - Subsea - Subsea Control Systems	Internal Leak	5	1	6	30	1
Pipe & Test Rams - BOP Stack	Plugged	5	1	3	15	1
Pipe & Test Rams - BOP Stack	Mechanical Failure	5	1	3	15	2
Pipe & Test Rams - BOP Stack	Wear	5	1	6	30	2
Pipe & Test Rams - BOP Stack	Corrosion / Erosion	5	1	6	30	1
Pipe & Test Rams - BOP Stack	Loss of Function (general)	5	1	3	15	2

Table 3-3 shows the equipment failure modes with an occurrence ranking greater than or equal to 3. These are the most frequently occurring equipment failures. Occurrence results from this FMECA range from 1–4. The Blind Shear Ram contributes to the most functional failures.

Table 3-3: Failure Modes with Occurrence ≥ 3

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Control Panels - Surface Control Systems	Erratic output	4	4	3	48	1
Control Panels - Surface Control Systems	Erratic output	10	4	3	120	15
Control Panels - Surface Control Systems	Fails to respond to input	4	4	3	48	1
Control Panels - Surface Control Systems	Fails to respond to input	10	4	3	120	14
Control Panels - Surface Control Systems	Processing error	4	4	3	48	1
Control Panels - Surface Control Systems	Processing error	10	4	3	120	14
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Loss of Hydraulic Power	10	3	3	90	3
Blind Shear Ram - BOP Stack	External Leak / Rupture	10	3	4	120	10
Blind Shear Ram - BOP Stack	Internal Leak	10	3	3	90	9
Blind Shear Ram - BOP Stack	Mechanical Failure	10	3	7	210	18
Blind Shear Ram - BOP Stack	Loss of Function (general)	10	3	7	210	19

Table 3-4 shows the equipment failure modes with a detection ranking greater than or equal to 6, which are the hardest to detect. This list helps identify the equipment-level failure modes for which additional MIT activities may be needed. Detection results from this FMECA range from 1–10. Connectors have the worst detectability rating, followed by the subsea accumulators, blind shear ram, and the shear ram.

Table 3-4: Failure Modes with Detection ≥ 6

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Connectors - BOP Stack	Loss of Function (general)	10	1	10	100	4
Accumulators - Subsea - Subsea Control Systems	Mechanical Failure (Internal wear is included)	4	2	7	28	1
Accumulators - Subsea - Subsea Control Systems	Mechanical Failure (Internal wear is included)	10	2	7	140	13
Blind Shear Ram - BOP Stack	Mechanical Failure	10	3	7	210	18
Blind Shear Ram - BOP Stack	Loss of Function (general)	10	3	7	210	19
Shear Ram - BOP Stack	Mechanical Failure	10	2	7	140	8
Shear Ram - BOP Stack	Loss of Function (general)	10	2	7	140	8
HPU - Surface Control Systems	Internal Leak	5	1	6	30	1
HPU - Surface Control Systems	Internal Leak	10	1	6	60	18
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Corrosion/ Erosion - No Indication of Corrosion/ Erosion (Stainless Steel)	4	1	6	24	1

Table 3-4: Failure Modes with Detection ≥ 6 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Blue & Yellow Control Systems - Lower Valve Section - Subsea Control Systems	Corrosion/ Erosion - No Indication of Corrosion/ Erosion (Stainless Steel)	10	1	6	60	13
Accumulators - Subsea - Subsea Control Systems	Internal Leak	5	1	6	30	1
Accumulators - Subsea - Subsea Control Systems	Internal Leak	4	1	6	24	1
Accumulators - Subsea - Subsea Control Systems	Internal Leak	10	1	6	60	26
Secondary (ROV) - Subsea Control Systems	Loss of function (general)	4	2	6	48	1
Secondary (ROV) - Subsea Control Systems	Loss of function (general)	10	2	6	120	10
Emergency Control Systems (Autoshear/Dead man) - Subsea Control Systems	Loss of function (general)	10	2	6	120	8
Annulars - BOP Stack	Wear	10	1	6	60	10
Annulars - BOP Stack	Corrosion/ Erosion	10	1	6	60	2
Annulars - BOP Stack	Loss of Function (general)	10	1	6	60	10
Blind Shear Ram - BOP Stack	Wear	10	1	6	60	12
Blind Shear Ram - BOP Stack	Corrosion/ Erosion	10	1	6	60	5
Shear Ram - BOP Stack	Wear	10	1	6	60	2

Table 3-4: Failure Modes with Detection ≥ 6 (cont'd)

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Shear Ram - BOP Stack	Corrosion / Erosion	10	1	6	60	2
Pipe & Test Rams - BOP Stack	Wear	5	1	6	30	2
Pipe & Test Rams - BOP Stack	Wear	10	1	6	60	6
Pipe & Test Rams - BOP Stack	Corrosion/ Erosion	5	1	6	30	1
Pipe & Test Rams - BOP Stack	Corrosion/ Erosion	10	1	6	60	5
Choke & Kill Lines & Valves - BOP Stack	Wear	10	1	6	60	8
Choke & Kill Lines & Valves - BOP Stack	Corrosion/ Erosion	10	1	6	60	6
Connectors - BOP Stack	Internal Leak	10	1	6	60	4
Connectors - BOP Stack	Mechanical Failure	10	1	6	60	9
Connectors - BOP Stack	Corrosion/ Erosion	7	2	6	84	2
Connectors - BOP Stack	Corrosion/ Erosion	8	1	6	48	2
Connectors - BOP Stack	Loss of Function (general)	7	2	6	84	2
Connectors - BOP Stack	Loss of Function (general)	8	1	6	48	2

Table 3-5 shows the equipment failure modes with a severity ranking of 10, an occurrence ranking greater than or equal to 3 and a detection ranking less than or equal to 5. These are the equipment failures that occur most frequently and could result in the highest severity but are easy to detect.

Table 3-5: Failure Modes with S = 10, O ≥ 3, and D ≤ 5

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Control Panels - Surface Control Systems	Erratic output	10	4	3	120	15
Control Panels - Surface Control Systems	Fails to respond to input	10	4	3	120	14
Control Panels - Surface Control Systems	Processing error	10	4	3	120	14
Blue & Yellow Control Systems - EH Section - Subsea Control Systems	Loss of Hydraulic Power	10	3	3	90	3
Blind Shear Ram - BOP Stack	External Leak / Rupture	10	3	4	120	10
Blind Shear Ram - BOP Stack	Internal Leak	10	3	3	90	9

Table 3-6 shows the equipment failure modes with a severity ranking of 10, an occurrence ranking greater than or equal to 3 and a detection ranking greater than 5. These are the equipment failures that occur most frequently and could result in the highest severity and are the hardest to detect.

Table 3-6: Failure Modes with S = 10, O ≥ 3, and D > 5

Major Component/ Subsystem	Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)	# of Effects (Functional Failures)
Blind Shear Ram - BOP Stack	Mechanical Failure	10	3	7	210	18
Blind Shear Ram - BOP Stack	Loss of Function (general)	10	3	7	210	19

The effect of each equipment level failure is linked to a functional failure. Table 3-7 lists the top 25% of effects/functional failures with the highest average RPN for all of the equipment failures associated with that functional failure. Failing to shear the pipe has the six worst average RPN scores.

Table 3-7: Functional Failures with Highest Average RPN

Effect	# of Occurrences	Cumulative FF RPN	Average FF RPN
Failure to Shear Pipe - Failure to shear the drill pipe - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.2.1)	7	790	113
Failure of Shear Ram to Seal On Demand - Failure to seal the wellbore - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.4.1)	9	930	103
Failure to Shear Pipe - Failure to shear the drill pipe - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.3.2)	10	1030	103
Failure of Shear Ram to Seal On Demand - Failure to seal the wellbore - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.3.1)	8	810	101
Failure to Shear Pipe - Failure to shear the drill pipe - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.2.1)	10	940	94
Failure of Shear Ram to Seal On Demand - Failure to seal the wellbore - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.3.1)	9	840	93
Failure to Maintain Adequate Sealing Pressure on Annular/Blind-Shear Ram - Failure to close on open hole through blind-shear rams or annular - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.1.5)	9	780	87
Failure to Maintain Sealing Pressure on Shear Ram - Failure to seal the wellbore - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.4.2)	9	780	87
Failure of Connector Integrity - Inadequate LMRP Connection - Connect BOP and LMRP at Landing (linked to 1.11.2.2)	2	168	84
Failure to Maintain Sealing Pressure on Shear Ram - Failure to seal the wellbore - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.3.2)	8	660	83
Failure of LMRP Connector to Disengage - Failure to Disconnect the LMRP - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.7.2)	2	160	80
Actuates Too Slowly on Demand - Closes too slowly - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.5.1)	22	1695	77

Table 3-7: Functional Failures with Highest Average RPN (cont'd)

Effect	# of Occurrences	Cumulative FF RPN	Average FF RPN
Failure to Maintain Sealing Pressure on Shear Ram - Failure to seal the wellbore - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.3.2)	9	690	77
Actuates Too Slowly on Demand - Closes too slowly - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.5.1)	23	1725	75
Unintentional Operation - Unintentional closing / opening - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.4.1)	9	670	74
Failure to Close Annular / Blind-Shear Ram on Demand - Failure to close on open hole through blind-shear rams or annular - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.1.3)	17	1250	74
External Leak - Loss of containment - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.6.1)	10	730	73
External Leak - Loss of containment - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.7.1)	10	730	73
Failure of Annular / Blind-Shear Ram to Seal on Demand - Failure to close on open hole through blind-shear rams or annular - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.1.4)	14	1020	73
Actuates Too Slowly on Demand - Closes too slowly - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.6.1)	17	1190	70
Actuates Too Slowly on Demand - Closes too slowly - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.4.1)	22	1525	69
External Leak - Loss of containment - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.6.1)	11	760	69
Unintentional Manual Disconnect Signal - Unintentional disconnect of the LMRP/BOP - Disconnect the LMRP/BOP (linked to 1.8.2.2)	8	540	68
Unintentional Operation - Unintentional closing / opening - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.4.1)	11	730	66
Failure of LMRP Connector to Properly Lock and Seal - Inadequate LMRP Connection - Connect BOP and LMRP at Landing (linked to 1.11.2.1)	3	196	65

Table 3-7: Functional Failures with Highest Average RPN (cont'd)

Effect	# of Occurrences	Cumulative FF RPN	Average FF RPN
Unintentional Operation - Unintentional closing / opening - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.2.1)	9	570	63

Table 3-8 lists the top 25% of effects/functional failures that are most frequently linked to equipment failures. Failing to supply hydraulic fluid is by far the most frequently occurring functional failure.

Table 3-8: Functional Failures with Greatest Occurrences Due to Equipment Failures

Effect	# of Occurrences	Cumulative FF RPN	Average FF RPN
Failure to Supply Hydraulic Fluid & Pressure to Shear Ram - Failure to close - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.2.1)	31	1325	43
Failure of Hydraulic Fluid to Disconnect - Failure to disconnect the LMRP/BOP - Disconnect the LMRP/BOP (linked to 1.8.1.3)	30	1215	41
Failure of Hydraulic Fluid to Disconnect - Failure to Disconnect the LMRP - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.7.3)	29	1095	38
Failure to Supply Hydraulic Fluid & Pressure to Shear Ram - Failure to close - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.1.2)	28	1170	42
Failure to Supply Hydraulic Fluid & Pressure to Hang-off Ram - Failure of hang-off ram to close - Hang-off the drill pipe on a ram BOP and control the wellbore (linked to 1.4.1.2)	28	1095	39
Failure to Supply Hydraulic Fluid & Pressure to Pipe Ram or C&K Valves When Demanded - Failure to close on drill pipe through pipe rams - Close and seal on the drill pipe and allow circulation on demand (linked to 1.1.2.2)	28	1095	39
Failure to Supply Hydraulic Fluid & Pressure to Shear Ram - Failure to close - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.1.2)	28	1095	39
Failure to Supply Hydraulic Fluid & Pressure to Shear Ram - Failure to shear the drill pipe - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.3.1)	28	1095	39

Table 3-8: Functional Failures with Greatest Occurrences Due to Equipment Failures (cont'd)

Effect	# of Occurrences	Cumulative FF RPN	Average FF RPN
Failure to Supply Hydraulic Fluid & Pressure to Annular/Blind-Shear Ram or C&K Valves - Failure to close on open hole through blind-shear rams or annular - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.1.2)	27	1065	39
Failure to Supply Hydraulic Fluid & Pressure to C&K Valves - Failure to seal wellbore after drill pipe disconnect - Circulate the well after drill pipe disconnect (linked to 1.9.4.2)	27	1065	39
Failure to Supply Hydraulic Fluid & Pressure to Annulars - Failure to close annulars - Strip the drill string using the annular BOP(s) (linked to 1.3.1.2)	27	975	36
Failure to Supply Hydraulic Fluid & Pressure to C&K Valves - Failure to circulate - Circulate the well after drill pipe disconnect (linked to 1.9.1.2)	27	443	16
Failure to Supply Hydraulic Fluid & Pressure to C&K Valves - Failure to circulate - Circulate across the BOP stack to remove trapped gas (linked to 1.10.1.2)	26	1045	40
Failure to Supply Hydraulic Fluid & Pressure to Annular & C&K Valves When Demanded - Failure to close on drill pipe through annular(s) - Close and seal on the drill pipe and allow circulation on demand (linked to 1.1.1.2)	26	915	35
Actuates Too Slowly on Demand - Closes too slowly - Emergency Operation - EDS - Shear the drill pipe and seal the wellbore (linked to 1.7.5.1)	23	1655	72
Actuates Too Slowly on Demand - Closes too slowly - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.5.1)	22	1625	74
Actuates Too Slowly on Demand - Closes too slowly - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.4.1)	22	1475	67
Actuates Too Slowly on Demand - Closes too slowly - Close and seal on the drill pipe and allow circulation on demand (linked to 1.1.7.1)	22	845	38
Failure to Provide Control Signal - Failure to Arm - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.1.1)	18	890	49
Failure to Close Annular / Blind-Shear Ram on Demand - Failure to close on open hole through blind-shear rams or annular - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.1.3)	17	1200	71

Table 3-8: Functional Failures with Greatest Occurrences Due to Equipment Failures (cont'd)

Effect	# of Occurrences	Cumulative FF RPN	Average FF RPN
Actuates Too Slowly on Demand - Closes too slowly - Emergency Operation - Auto-Shear - Shear the drill pipe and seal the wellbore (linked to 1.6.6.1)	17	1120	66
Failure to Provide Control Signal to Annular / Blind-Shear Ram & C&K Valves When Demanded - Failure to close on open hole through blind-shear rams or annular - Close and seal on open hole and allow volumetric well control operations on demand (linked to 1.2.1.1)	16	700	44
Failure to Provide Control Signal to C&K Valves when Demanded - Failure to circulate - Circulate across the BOP stack to remove trapped gas (linked to 1.10.1.1)	16	700	44
Failure to Provide Control Signal to C&K Valves when Demanded - Failure to seal wellbore after drill pipe disconnect - Circulate the well after drill pipe disconnect (linked to 1.9.4.1)	16	700	44
Failure to Provide Control Signal to Shear Ram When Demanded - Failure to close - Controlled operation - Shear the drill pipe and seal the wellbore (linked to 1.5.1.1)	16	700	44
Failure to Provide Disconnect Signal (automatically or manually) - Failure to disconnect the LMRP/BOP - Disconnect the LMRP/BOP (linked to 1.8.1.1)	16	680	43
Failure to Provide Control Signal to C&K Valves when Demanded - Failure to circulate - Circulate the well after drill pipe disconnect (linked to 1.9.1.1)	16	280	18